



Europäisches Patentamt  
European Patent Office  
Office européen des brevets



(11) **EP 1 713 195 A1**

(12) **EUROPEAN PATENT APPLICATION**  
published in accordance with Art. 158(3) EPC

(43) Date of publication:  
**18.10.2006 Bulletin 2006/42**

(51) Int Cl.:  
**H04L 9/08 (2006.01)**

(21) Application number: **04762105.7**

(86) International application number:  
**PCT/CN2004/000969**

(22) Date of filing: **19.08.2004**

(87) International publication number:  
**WO 2005/076517 (18.08.2005 Gazette 2005/33)**

(84) Designated Contracting States:  
**CH DE FR GB LI**

(30) Priority: **02.02.2004 CN 200410013996**

(71) Applicant: **University of Science and Technology of China**  
**Hefei,**  
**Anhui 230026 (CN)**

(72) Inventors:  
• **Han, Zhengfu**  
**Anhui 230026 (CN)**

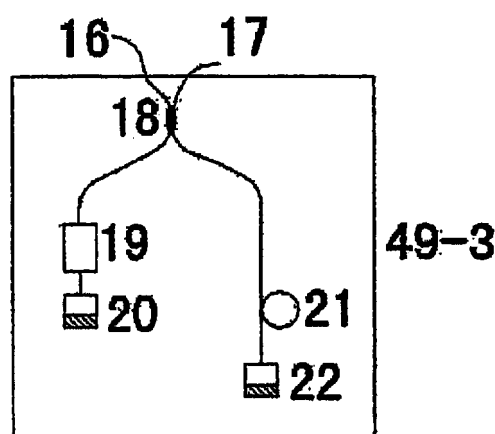
• **Zhu, Bing**  
**Anhui 230026 (CN)**  
• **Mo, Xiaofan**  
**Anhui 230026 (CN)**  
• **Guo, Guangcan**  
**Anhui 230026 (CN)**

(74) Representative: **Barth, Stephan Manuel**  
**Reinhard-Skühra-Weise & Partner GbR,**  
**Patentanwälte**  
**Friedrichstrasse 31**  
**80801 München (DE)**

(54) **A POLARISATION-CONTROLLED ENCODING METHOD, ENCODER AND QUANTUM KEY DISTRIBUTION SYSTEM**

(57) The invention relates to a polarization-controlled encoding method, encoder and quantum key distribution system, which is **characterized in that** polarization maintaining light path or 90 degree rotation Faraday mirror are used inside the encoder to keep the polarization of the output pulses same, and that in the quantum key distribution system employing the polarization-controlled encoder the pulse emitted from transmitter is unidirectional-transmitted to receiver and then quantum key distribution is implemented using interference in the pulses according to the quantum key distribution protocol. The quantum key distribution system using the polarization-controlled encoder of the invention has the ability of avoiding the wiretapping to transmitter, receiver and quantum channel. Detection units each of which separates reversed photon from other photons are added at the out port of the transmitter and the in port of receiver, respectively, so that Trojan horse is prevented from entering and photons with phase modulated information are prevented from leaving the safe area in receiver. Unconditionally safe key distribution can be accomplished by using the quantum key distribution system of the invention.

**Fig. 3**



**EP 1 713 195 A1**

## Description

### Field of the Invention

[0001] This invention relates to the field of secure optical communication, and more particularly to an encoding method and device in quantum key distribution system.

### Description of the Related Art

[0002] Early encoding scheme of quantum key distribution is based upon photon polarization. This scheme is fit for free-space communication instead of fiber communication. That's because the symmetry of normal fiber is not good and the interference in transmission path disturbs the polarization state, the photon polarization will be random changed during transmission in it. US 5307410 disclosed a phase encoding scheme of quantum key distribution which bases on a pair of unbalanced Mach-Zehnder interferometers. Because the optical pulses pass through the different arms of the different interferometers in transmitter and receiver, the disturbance they suffered is not exactly identical to each other and can't be counteracted. The stability and anti-jamming ability of the system is bad. Also because two photon pulses pass through the different arms of transmitter's interferometer, the polarization relation between two photon pulses is uncertain when they enter the quantum channel. This system is sensitive to the disturbance in quantum channel, especially for long distance quantum key distribution. A lot of variations of this scheme have no essential improvement.

[0003] In order to improve the stability of above scheme, a publication in Applied Physics Letters (vol77 (No.7), 793 (1997)) discloses a solution that uses Faraday mirrors in receiver to reflect optical pulses back to the transmitter so that the interfering pulses follow exactly the same optical path. This will get self-balancing effect. This scheme assumes that the disturbance is same when optical pulses pass through the same position twice and then they are counteracted to achieve the object of anti-jamming and stability. In fact, it works only for short distance and low disturbance frequency. When transmission distance increases, the time slot in which the optical pulses pass through the same position twice also increases, and the anti-jamming ability decreases. Furthermore, because the optical pulses pass through the same quantum channel twice, the loss of total optical path should be double. This can be solved by method with strong coming laser pulse and attenuating it to single photon level after reflecting. But, it can be used only for attenuated laser source. The ideal optical source for quantum key distribution is single photon source. When the single photon source becomes available, the maximum transmission distance should be half of the unidirectional scheme. On the other hand, an eavesdropper can attenuate the strong coming laser pulse before it

reach the communication receiver, and then combine it with a spy laser pulse whose wavelength is close to the original one to make the total power as same as before, that will make power monitor of no effect. When the signals come back, the spy signal can be separated to get the information of communication receiver, and the original signal will be still transmitted to transmitter through an "ultra-low loss channel" so that the eavesdropper won't be detected. This is deadly for information security.

### Summary of the Invention

[0004] The present invention provides a polarization-controlled quantum key distribution encoding method, encoder and system. It can provide unconditional secure key distribution between two users.

[0005] The polarization-controlled encoding method comprises the steps of: splitting an injected optical pulse into two optical pulses traveling along two different paths; and relatively delaying the two optical pulses; recombining the delayed pulses in one output path; wherein the method further comprises a step of phase modulating at least one pulse after the splitting step or recombining step according to a quantum key distribution protocol, and a step of controlling the polarization states of two pulses during the course from the splitting to the recombining to make the polarization states same after recombining.

[0006] Preferably, the step of controlling comprises: keeping the polarization states of two optical pulses fixedness during the course from the splitting to the recombining.

[0007] Preferably, the step of controlling comprises: making the two optical pulses reflected odd times by 90 degree Faraday mirrors separately, and passing them through the same path even times respectively.

[0008] Preferably, the step of controlling comprises: making one optical pulse outputted directly and another optical pulse reflected even times by 90 degree Faraday mirrors, and passing the reflected pulse through the same path even times.

[0009] First polarization-controlled encoder constructed by using the method comprises: a first polarization-maintained beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths; a delay line for relatively delaying the two optical pulses; a second polarization-controlled beam splitter for recombining the delayed pulses in one output path; and at least one phase modulator arranged on at least one path of the two different paths and the output path, wherein the two different paths are polarization-maintained paths.

[0010] Second polarization-controlled encoder constructed by using the method comprises: a polarization-maintained beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths; a polarization-maintained delay line arranged on one of the two different paths for relatively delaying the two optical pulses; at least one mirror for reflecting the delayed plus-

es to the polarization-maintained beam splitter to recombine the delayed pulses in one output path; and at least one phase modulator arranged on at least one of the two different paths and the output path, wherein the two different paths are polarization-maintained paths.

**[0011]** Third polarization-controlled encoder constructed by using the method comprises: a beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths; a delay line arranged on one of the two different paths for relatively delaying the two optical pulses; two 90 degree Faraday mirrors for respectively reflecting the delayed pulses back the beam splitter to recombine the delayed pulses in one output path; and at least one phase modulator arranged on at least one of the different paths and the output path.

**[0012]** Fourth polarization-controlled encoder constructed by using the method comprises: a variable polarization-maintained beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths and outputting one optical pulse directly; a first mirror for reflecting another optical pulse back the variable polarization-maintained beam splitter and passing it through the variable polarization-maintained beam splitter; a second mirror for reflecting the pulse passed through the variable polarization-maintained beam splitter back, wherein the variable polarization-maintained beam splitter recombines the reflected pulse with the outputted pulse in one output path; a polarization-maintained delay line arranged on the paths between the first and second mirrors; and at least one phase modulator arranged on at least one of the two different paths and the output path, wherein the paths between the first and second mirrors are polarization-maintained paths.

**[0013]** Fifth polarization-controlled encoder constructed by using the method comprises: a beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths and outputting one optical pulse directly; a first 90 degree Faraday mirror for reflecting another optical pulse back the beam splitter and passing it through the beam splitter; a second 90 degree Faraday mirror for reflecting the pulse passed through the beam splitter back, wherein the beam splitter recombines the reflected pulse with the outputted pulse in one output path; a delay line arranged on the paths between the first and second mirrors; and at least one phase modulator arranged on at least one of the paths between the first and second mirrors and the output path.

**[0014]** A quantum key distribution system comprises: a transmitter side polarization-controlled encoder for splitting an optical pulse emitted from a pulse light source into two optical pulses traveling along two different paths, relatively delaying the two optical pulses and recombining the optical pulses in one output path, wherein at least one of the optical pulses is phase-modulated according to a quantum key distribution protocol; at least one quantum channel for unidirectional-transmitting the optical pulses output from the transmitter side polarization-controlled encoder; a receiver side polarization-controlled

encoder for receiving the optical pulses from the quantum channel, splitting each of the optical pulses into two optical pulses which form a group and travel along two different paths, relatively delaying the two optical pulses on the basis of the quantum key distribution protocol, and recombining the two optical pulses in one output path, wherein at least one of the received optical pulses, the split optical pulses, the delayed pulses is phase-modulated before recombined in one output path according to the quantum key distribution protocol; and a single photon detector for measuring at least one superposition interference of two pulses come from different groups and distributing a quantum key according to the quantum key distribution protocol.

**[0015]** Preferably, the system further comprises a return photon separating and detecting unit that is added in the output of a transmitter or in the input of a receiver, the return photon separating and detecting unit comprises an optical circulator and a single photon detector, wherein an input port of the unit connects with an output port of the encoder, and an output port of the unit connects with the quantum channel, and a reverse output port of the unit connects with an input port of the single photon detector.

**[0016]** Preferably, the return photon separating and detecting unit further comprises a band pass filter arranged before the input of the circulator.

**[0017]** The quantum channel may be optical waveguide, fiber, free space, separating optical component or propagation channel made up of above.

**[0018]** Comparing with existing encoder bases on Mach-Zehnder interferometer, the encoder of present patent controls polarization state of optical pulse inside itself. This makes it insensitive to disturbance on itself so that the environment requirements of quantum key distribution system reduced largely. Because two pulses injected into the quantum channel are controlled at same polarization state, the disturbance they suffered when transmitting is compensated before they enter the receiver. That means signal transmitting is independent of channel disturbance. The stability of system is improved greatly. In the encoder with 90 degree Faraday mirrors according to the invention, the pulse passes through the phase modulator twice with orthogonal polarization. If the duration of phase modulating signal is larger than the time slot during which the pulse pass through modulator twice, the modulation will be independent of polarization. So the polarization-dependent modulator can be used to achieve polarization-independent modulation. The requirement of modulation rate will also be reduced. In the encoder with polarization-maintained beam splitter according to the invention, since polarization of optical pulses is maintained, polarization-dependent modulator can be used.

**[0019]** In quantum key distribution system according to the invention, return photon separating and detecting unit can be added to separate and detect any reverse transmitted photons. This will not only prevent spy pho-

tons from entering the encoder to eavesdrop information but also detect whether there is an eavesdropper. Since single photon detector and circulator have a certain range of response wavelength, optical band pass filter can be added in the quantum key distribution system so that optical pulses with wavelength in working spectrum can pass through the filter, pulses with wavelength out of working spectrum can not pass through the filter. This can compensate the disadvantage that single photon detector and circulator don't have enough response band.

### **Brief Description of the Drawings**

#### **[0020]**

FIG. 1 is a block diagram of Mach-Zehnder interferometer based polarization-controlled with polarization-maintained paths.

FIG. 2 is a block diagram of polarization-controlled encoder with mirrors and polarization-maintained paths.

FIG. 3 is a block diagram of polarization-controlled encoder with 90 degree Faraday mirrors.

FIG. 4 is a block diagram of another type of polarization-controlled encoder with 90 degree Faraday mirrors.

FIG. 5 is a block diagram of polarization-controlled encoder with 90 degree Faraday mirrors in which the modulator is located in the output path.

FIG. 6 is a block diagram of polarization-controlled encoder with variable beam splitter, mirrors and polarization-maintained paths.

FIG. 7 is a block diagram of polarization-controlled encoder with variable beam splitter and 90 degree Faraday mirrors.

FIG. 8 shows one return photon separating and detecting unit.

FIG. 9 shows another return photon separating and detecting unit which has band pass filter.

FIG. 10 is a block diagram of quantum key distribution system whose kernel part is polarization-controlled encoder and the quantum channel is optical fiber.

### **Detailed Description of the Preferred Embodiment**

#### **First Embodiment**

**[0021]** The first configuration of polarization-controlled encoder in quantum key distribution system is shown in FIG. 1. It includes two  $2 \times 2$  —  $3dB$  polarization-maintained beam splitters **3** and **6**, one polarization-maintained phase modulator **5** and one polarization-maintained delay line **4**. These form a Mach-Zehnder interferometer. Any one of the two ports **1** and **2** which are in the same side of  $3dB$  beam splitter **3** can be the input port of polarization-controlled encoder. Any one of the two ports **7** and **8** which are in the same side of  $3dB$  beam

splitter **6** can be the output port. The modulator **5** and delay line **4** (no sequencing) can be inserted into one arm of the Mach-Zehnder interferometer or two arms separately. When the system works, an optical pulse is injected into port **1** or **2** of beam splitter **3** and divided into two pulses. One pulse passes through the modulator **5**. Another one pass through the delay line **4**. Then they are recombined by beam splitter **6** and output from port **7** or **8**. Because all the paths are polarization-maintained, the output pulses have same polarization state. When the modulator **5** and delay line **4** are in the same arm of Mach-Zehnder interferometer, the result is the same.

#### **Second Embodiment**

**[0022]** The second configuration of polarization-controlled encoder in quantum key distribution system is shown in FIG. 2. It includes one  $2 \times 2$  —  $3dB$  polarization-maintained beam splitter **11**, two mirrors **13** and **15**, one polarization-maintained phase modulator **12** and one polarization-maintained delay line **14**. These two ports **9** and **10** which are in the same side of  $3dB$  beam splitter **11** are input and output ports of polarization-controlled encoder respectively. One of the two ports which are in the other side of  $3dB$  beam splitter **11** connects with polarization-maintained phase modulator **12** and mirror **13** in turn. The other port connects with polarization-maintained delay line **14** and mirror **15** in turn. A variation of above configuration is to connect one port of beam splitter with modulator **12**, delay line **14** and mirror in turn, and connect the other port of beam splitter with only a mirror. When the system works, an optical pulse is injected into port **9** of polarization-maintained beam splitter **11** and divided into two pulses. One pulse pass through the delay line **14** and reflected back by mirror **15**. The other pulse pass through the modulator **12** and reflected back by mirror **13**. Then they are recombined by beam splitter **11** and output from port **10**. Because all the paths are polarization-maintained, the output pulses have same polarization state. The variation of above configuration has same result. Either port **9** is input and port **10** is output or reverse have same result.

#### **Third Embodiment**

**[0023]** The third configuration of polarization-controlled encoder in quantum key distribution system is shown in FIG. 3. It includes one  $2 \times 2$  —  $3dB$  beam splitter **18**, two 90 degree Faraday mirrors **20** and **22**, one phase modulator **19** and one delay line **21**. The two ports **16** and **17** which are in the same side of  $3dB$  beam splitter **18** are input and output ports of polarization-controlled encoder respectively. One of the two ports which are in the other side of  $3dB$  beam splitter **18** connects with phase modulator **19** and 90 degree Faraday mirror **20** in turn. The other port connects with delay line **21** and 90 degree Faraday mirror **22** in turn. When the system works, an optical pulse is injected into port **16** of beam

splitter **18** and divided into two pulses. One pulse pass through the delay line **21** and reflected back by 90 degree Faraday mirror **22**. The other pulse pass through the modulator **19** and reflected back by 90 degree Faraday mirror **20**. Then they are recombined by beam splitter **18** and output from port **17**. Because the two pulses are reflected by 90 degree Faraday mirrors and pass through their own path even times, the output pulses have same polarization state. Either port **17** is input and port **16** is output or reverse has same result.

#### Fourth Embodiment

**[0024]** The configuration of a variation of the third embodiment is shown in FIG. 4. The difference from the third embodiment is one port of beam splitter connects with modulator **19**, delay line **21** (position of them can be exchanged) and 90 degree Faraday mirror **22** in turn, and the other port of beam splitter connects with a 90 degree Faraday mirror **20**. When the system works, an optical pulse is injected into port **16** of beam splitter **18** and divided into two pulses. One pulse pass through the phase modulator **19** and delay line **21** (no sequencing) and reflected back by 90 degree Faraday mirror **22**. The other pulse reflected back by 90 degree Faraday mirror **20**. Then they are recombined by beam splitter **18** and output from port **17**. Because the two pulses are reflected by 90 degree Faraday mirrors and pass through their own path even times, the output pulses have same polarization state. Either port **17** is input and port **16** is output or reverse has same result.

#### Fifth Embodiment

**[0025]** The fourth configuration of polarization-controlled encoder in quantum key distribution system is shown in FIG. 6. It includes one  $2 \times 2$  polarization-maintained variable beam splitter **25**, two mirrors **23** and **27**, one polarization-maintained phase modulator **24** and one polarization-maintained delay line **26**. One of the two ports which are in the same side of variable beam splitter **25** is output port **28** of polarization-controlled encoder, and the other port connects with delay line **26** and mirror **27** in turn. One of the two ports which are in the other side of variable beam splitter **25** is input port **29** of polarization-controlled encoder, and the other port connects with polarization-maintained phase modulator **24** and mirror **23** in turn. A variation of above configuration is to connect one port of beam splitter with delay line **26** and modulator **24** (no sequencing) in turn, and connect the other port of beam splitter with only a mirror. When the system works, an optical pulse is injected into port **29** of polarization-maintained variable beam splitter **25** and divided into two pulses. One pulse exits directly from port **28** of polarization-maintained variable beam splitter **25**. The other pulse pass through the delay line **26** and reflected back by mirror **27**, and then pass through beam splitter **25** again and continue passing through modulator **24** and

reflected by mirror **23**, and then pass through the beam splitter **25** at third time and output from port **28**. When splitting the optical pulse, the splitting ratio of variable beam splitter is regulated to make the two pulses exit from port **28** have equal amplitude. Because all the paths are polarization-maintained, the output pulses have same polarization state. The variation of above configuration has same result. Either port **28** is input and port **29** is output or reverse has same result.

#### Sixth Embodiment

**[0026]** The fifth configuration of polarization-controlled encoder in quantum key distribution system is shown in FIG. 7. It includes one  $2 \times 2$  variable beam splitter **32**, two 90 degree Faraday mirrors **30** and **34**, one phase modulator **31** and one delay line **33**. One of the two ports which are in the same side of variable beam splitter **32** is output port of polarization-controlled encoder, and the other port connects with delay line **33** and 90 degree Faraday mirror **34** in turn. One of the two ports which are in the other side of variable beam splitter **32** is input port **36** of polarization-controlled encoder, and the other port connects with phase modulator **31** and 90 degree Faraday mirror **30** in turn. A variation of above configuration is to connect one port of beam splitter with delay line **33** and modulator **31** (no sequencing) in turn, and connect the other port of beam splitter with only a 90 degree Faraday mirror. When the system works, an optical pulse is injected into port **36** of variable beam splitter **32** and divided into two pulses. One pulse outputs directly from port **35** of variable beam splitter **32**. The other pulse pass through the delay line **33** and reflected back by 90 degree Faraday mirror **34**, and then passes through beam splitter **32** again and continue passing through modulator **31** and reflected by 90 degree Faraday mirror **30**, and then passes through the beam splitter **32** at third time and exits from port **35**. When splitting the optical pulse, the splitting ratio of variable beam splitter is regulated to make the two pulses output from port **35** have equal amplitude. Because the two pulses are reflected by 90 degree Faraday mirrors and pass through their own path even times, the output pulses have same polarization state. The variation of above configuration has same result. Either port **35** is input and port **36** is output or reverse have same result.

#### Seventh Embodiment

**[0027]** In above five configurations of polarization-controlled encoder, the phase modulator can be moved to output path to get the same result. For example, a polarization-controlled encoder with phase modulator in output path is shown in FIG. 5. It includes one  $2 \times 2$  - 3dB beam splitter **18**, two 90 degree Faraday mirrors **20** and **22**, one phase modulator **19** and one delay line **21**. Port **16** of the two ports which are in the same side of 3dB beam splitter **18** is input port of polarization-controlled

encoder, and the other port connects with modulator **19** as output port **17** of encoder. One of the two ports which are in the other side of 3dB beam splitter **18** connects with 90 degree Faraday mirror **20**, and the other port connects with delay line **21** and 90 degree Faraday mirror **22** in turn. When the encoder is used in receiver, the modulator which is located in output path must be moved to input path. For example, modulator **19** in encoder **49-5** must connect with port **16** instead of port **17**. When the system works, an optical pulse is injected into port **16** of beam splitter **18** and divided into two pulses. One pulse pass through the delay line **21** and reflected back by 90 degree Faraday mirror **22**. The other pulse is reflected back by 90 degree Faraday mirror **20**. Then they are re-combined by beam splitter **18**, pass through modulator **19** and exit from port **17**. Because these two pulses are reflected by 90 degree Faraday mirrors and pass through their own path even times, the output pulses have same polarization state. When this encoder is used in receiver, the modulator **19** which is located in output path must be moved to input path. Either in output path of transmitter or input path of receiver, the modulator need not be polarization-maintained.

#### Eighth Embodiment

**[0028]** The return photon separating and detecting unit in the quantum key distribution system is made up of optical circulator **38** and single photon detector **37**. The input port **39** of optical circulator is the input port of return photon separating and detecting unit. The output port **40** of optical circulator is the output port of return photon separating and detecting unit. The return photon injected into port **40** will be separated by circulator **38** and detected by single photon detector **37**. The configuration of the unit is shown in FIG. 8. When the system works, photons injected into port **39** of circulator pass through the circulator directly and exit from port **40**. If there are photons injected into port **40**, they will be prevented from exiting from port **39** but guided to single photon detector **37** by circulator **38** in order to detect whether there are spy photons or not. When this unit is used in receiver, single photon detector **37** could detect signal photon to get useful key information.

#### Ninth Embodiment

**[0029]** Since optical circulator and single photon detector have limited response spectrum, there may be photons whose wavelength is out of response spectrum enter the polarization-controlled encoder. A variation of the return photon separating and detecting unit is shown in FIG. 9. The difference from the above one is that an optical band pass filter **41** is added after input port **39**. When the system works, photons in response spectrum pass through the optical band pass filter freely, but other photons are blocked. This will improve the system's ability of resisting eavesdropping.

#### Tenth Embodiment

**[0030]** A quantum key distribution system including the polarization-controlled encoders, return photon separating and detecting unit, single photon detectors and optical pulse source is shown in FIG. 10. The transmitter is made up of single photon source **42** (it can be replaced by simulative single photon source which is made up of laser and attenuator), polarization-controlled encoder **43** and return photon separating and detecting unit **44**. The input port of encoder **43** (it can be encoder **49-1**, **49-2**, **49-3**, **49-6**, **49-7** or any variation of them) connects with the output port of single photon source **42**. The output port of encoder **43** connects with the input port of return photon separating and detecting unit **44** (it can be return photon separating and detecting unit **50-1** or **50-2**). The output port of unit **44** connects with quantum channel **45**.

**[0031]** The receiver is made up of polarization-controlled encoder **47** (it can be encoder **49-1**, **49-2**, **49-3**, **49-6**, **49-7** or any variation of them, wherein **49-3** or **49-7** is better), return photon separating and detecting unit **46** (it can be return photon separating and detecting unit **50-1** or **50-2**) and single photon detector **48**. Quantum channel **45** connects with the input port of unit **46**. The output port of unit **46** connects with the input port of encoder **47**. The output port of encoder **47** connects with single photon detector **48**.

**[0032]** The process of quantum key distribution will be described hereinafter. One single photon pulse (it can be obtained by attenuating high power laser to at most one photon per pulse in fact) which is emitted from single photon source **42** enters polarization-controlled encoder **43**, and then divided into two pulses and delayed. One of these two pulses is modulated according to quantum key distribution protocol. The output two pulses pass through return photon separating and detecting unit **44**, and then enter quantum channel **45** to be transmitted to the receiver. When arrived at receiver, these two pulses pass through return photon separating and detecting unit **46** and enter polarization-controlled encoder **47**. After that, each pulse is divided into two pulses again and delayed. Then these pulses are modulated according to quantum key distribution protocol and interfere. One of output interfering pulses is sent to single photon detector **48** to be measured (in order to reduce the dark count and disturbance from un-interfering pulses, the detector should work at gate mode, and the control signal of gate could be obtained from classical signal which is sent by transmitter), and the other passes through the return photon separating and detecting unit and be measured. According to the result of measurement and record of modulation, transmitter and receiver will get one bit of key. Repeat above steps, they will get any bit of keys with unconditional security. Because there are polarization-maintained paths and 90 degree Faraday mirrors in polarization-controlled encoder, two output pulses have same polarization state. That makes the system has good ability of anti-jamming. When the input and output

ports are the same in transmitter and receiver, circulator and Y beam splitter should be added to separate input and output signal. When the encoders in transmitter and receiver are **49-6** or **49-7**, splitting ratio of beam splitter should be regulated to make two output pulses have equal amplitude. This will reduce the error rate of final keys.

## Claims

1. A polarization-controlled encoding method comprising the steps of:

splitting an injected optical pulse into two optical pulses traveling along two different paths;  
relatively delaying said two optical pulses;  
recombining the delayed pluses in one path; and  
phase modulating at least one pulse after said splitting step or recombining step according to a quantum key distribution protocol,

wherein said method further comprises a step of controlling the polarization states of two pulses during the course from the splitting to the recombining to make said polarization states same after recombining.

2. The method of claim 1, wherein said step of controlling comprises:

keeping said polarization states of two optical pulses fixedness during the course from the splitting to the recombining.

3. The method of claim 1, wherein said step of controlling comprises:

making said two optical pulses reflected odd times by 90 degree Faraday mirrors separately, and passing them through the same path even times respectively.

4. The method of claim 1, wherein said step of controlling comprises:

making one optical pulse outputted directly and another optical pulse reflected even times by 90 degree Faraday mirrors, and passing the reflected pulse through the same path even times.

5. A polarization-controlled encoder constructed by using the method of claim 1 comprising:

a first polarization-maintained beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths;  
a delay line for relatively delaying said two opti-

cal pulses;

a second polarization-controlled beam splitter for recombining the delayed pluses in one output path; and

a phase modulator arranged on at least one path of said two different paths and said output path,

wherein said two different paths are polarization-maintained paths.

6. A polarization-controlled encoder constructed by using the method of claim 1 comprising:

a polarization-maintained beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths;  
a polarization-maintained delay line arranged on one of said two different paths for relatively delaying said two optical pluses;  
at least one mirror for reflecting the delayed pluses to the polarization-maintained beam splitter to recombine the delayed pulses in one output path; and  
a phase modulator arranged on at least one of said two different paths and said output path,

wherein said two different paths are polarization-maintained paths.

7. A polarization-controlled encoder constructed by using the method of claim 1 comprising:

a beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths;  
a delay line arranged on one of said two different paths for relatively delaying said two optical pluses;  
two 90 degree Faraday mirrors for respectively reflecting the delayed pluses back said beam splitter to recombine the delayed pulses in one output path; and  
a phase modulator arranged on at least one of said different paths and said output path.

8. A polarization-controlled encoder constructed by using the method of claim 1 comprising:

a variable polarization-maintained beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths and outputting one optical pulse directly;  
a first mirror for reflecting another optical pulse back said variable polarization-maintained beam splitter and passing it through said variable polarization-maintained beam splitter;  
a second mirror for reflecting the pulse passed through said variable polarization-maintained

beam splitter back, wherein said variable polarization-maintained beam splitter recombines the reflected pulse with the outputted pulse in one output path;

a polarization-maintained delay line arranged on the paths between the first and second mirrors; and

a phase modulator arranged on at least one of said two different paths and said output path,

wherein said paths between the first and second mirrors are polarization-maintained paths.

9. A polarization-controlled encoder constructed by using the method of claim 1 comprising:

a beam splitter for splitting an optical pulse into two optical pulses traveling along two different paths and outputting one optical pulse directly; a first 90 degree Faraday mirror for reflecting another optical pulse back said beam splitter and passing it through said beam splitter;

a second 90 degree Faraday mirror for reflecting the pulse passed through said beam splitter back, wherein said beam splitter recombines the reflected pulse with the outputted pulse in one output path;

a delay line arranged on the paths between the first and second mirrors; and

a phase modulator arranged on at least one of said paths between the first and second mirrors and said output path.

10. A quantum key distribution system comprising:

a transmitter side polarization-controlled encoder for splitting an optical pulse emitted from a pulse light source into two optical pulses traveling along two different paths, relatively delaying said two optical pulses and recombining said optical pulses in one output path, wherein at least one of said optical pulses is phase-modulated according to a quantum key distribution protocol;

at least one quantum channel for unidirectional-transmitting said optical pulses output from the transmitter side polarization-controlled encoder;

a receiver side polarization-controlled encoder for receiving said optical pulses from the quantum channel, splitting each of said optical pulses into two optical pulses which form a group and travel along two different paths, relatively delaying said two optical pulses on the basis of said quantum key distribution protocol, and recombining said two optical pulses in one output path, wherein at least one of the received optical pulses, the split optical pulses, the delayed pulses is phase-modulated before recombined in one

output path according to said quantum key distribution protocol; and

a single photon detector for measuring at least one superposition interference of two pulses come from different groups and distributing a quantum key according to said quantum key distribution protocol.

11. The system of claim 10, further comprises:

a return photon separating and detecting unit that is added in an output of a transmitter or in an input of a receiver, said return photon separating and detecting unit comprises an optical circulator and a single photon detector, wherein an input port of said unit connects with an output port of said encoder, and an output port of said unit connects with said quantum channel, and a reverse output port of said unit connects with an input port of said single photon detector.

12. The system of claim 11, wherein said return photon separating and detecting unit further comprises a band pass filter arranged before the input of said circulator.



Fig. 1

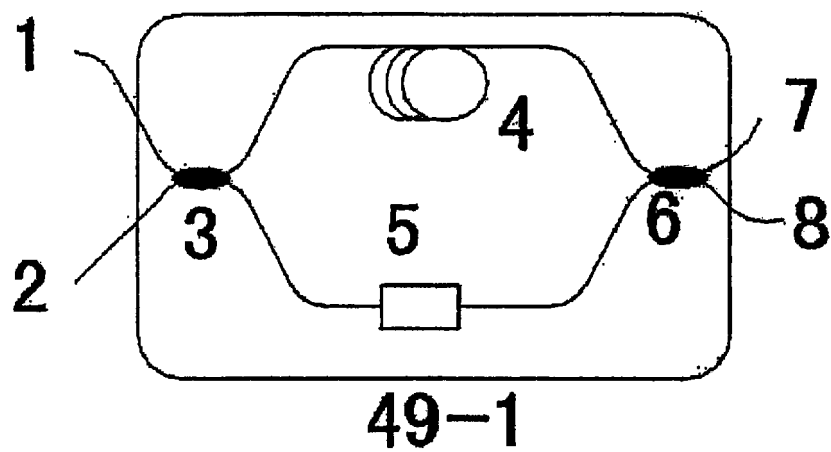


Fig. 2

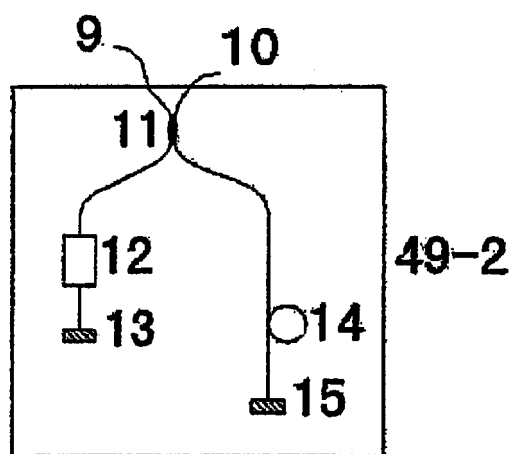


Fig. 3

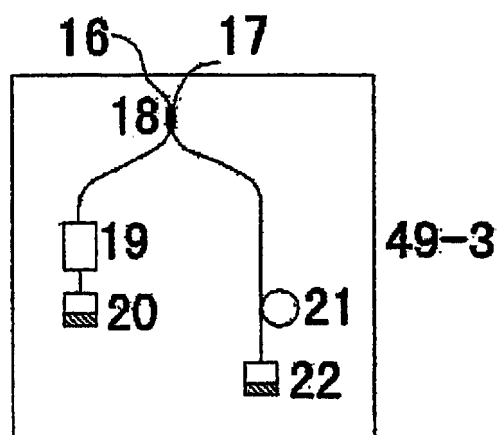


Fig. 4

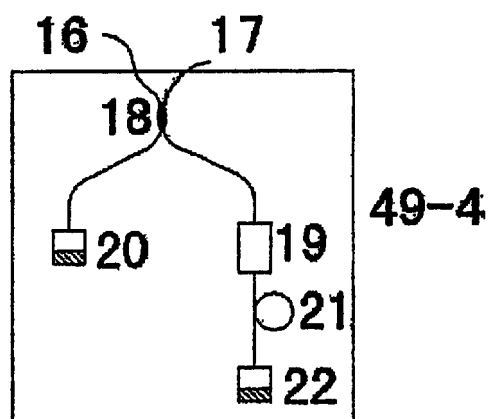


Fig. 5

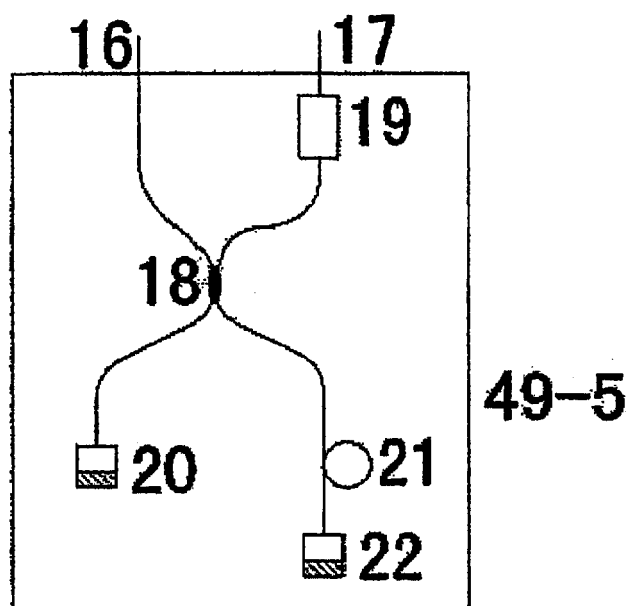


Fig. 6

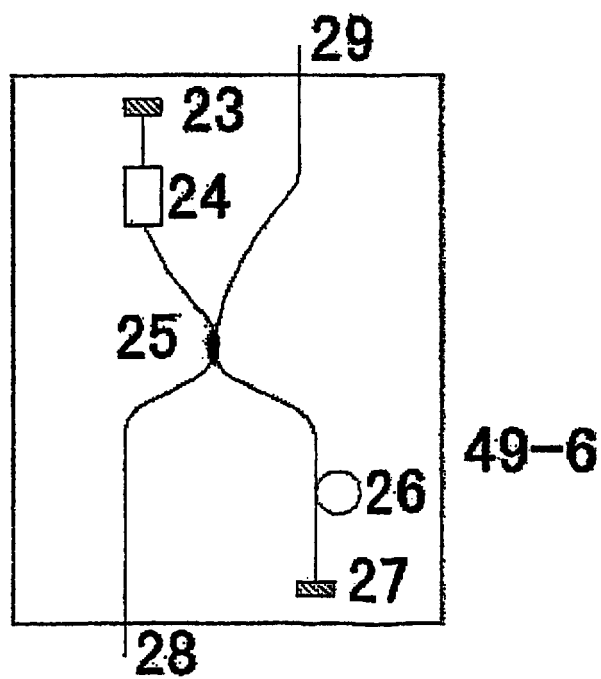


Fig. 7

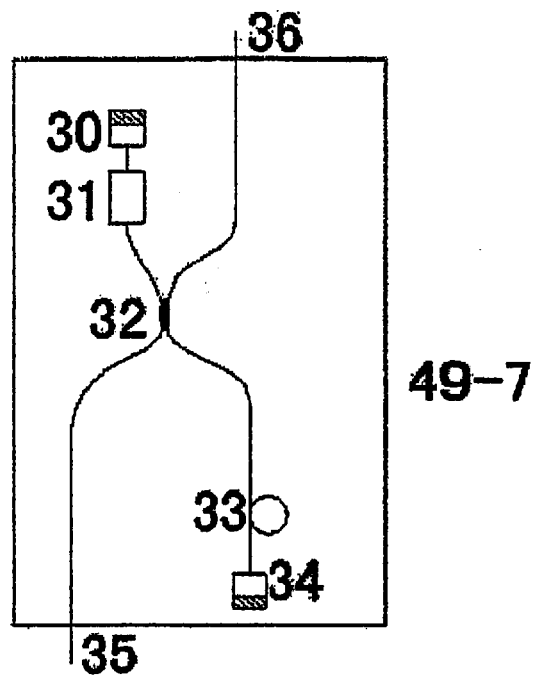


Fig. 8

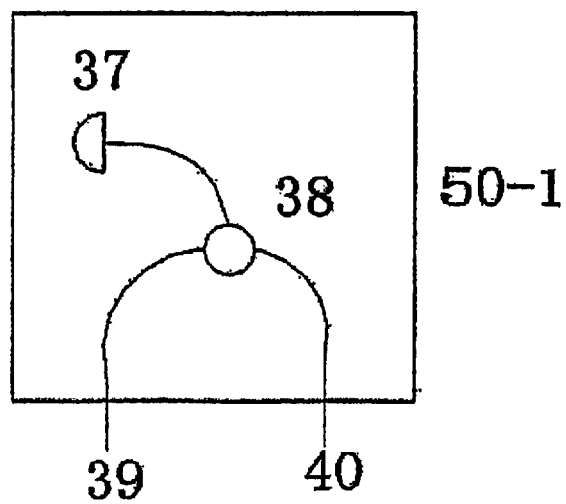


Fig. 9

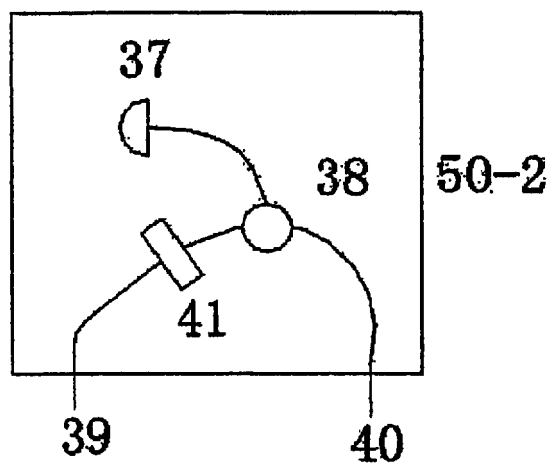
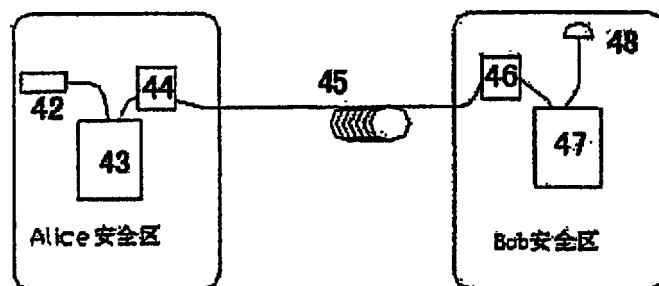


Fig. 10



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/CN2004/000969

## A. CLASSIFICATION OF SUBJECT MATTER

H04L9/08

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED G02B,H04L

Minimum documentation searched (classification system followed by classification symbols)

G02B26/08,H04L9/08,9/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

CHINA JOURNAL

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

quantum w cryptogra+, quantum w key w distribut+, polariz+, polaris+

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US6529601B1 (Paul D. Townsend, Ipswich (GB);04.Mar.2003,column4,line30 to column7,line50,Fig.1 to 4)	1、2、5—10
Y		4
X	US6438234B1(Nicolas Gisin, Geneva(CH) et al;20.Aug.2002,column2,line32 to column6,line 61,Fig.1 to 3)	1、3
X	US6188768B1(Donald Stimson Bethume, San Jose et al;13.Feb.2001,column3, line42 to column4,line35,Fig.1)	1
Y		4
X	CN1135820A(MINA) UK SEC FOR DEFENCE; (MINA) UK SEC STATE OR DEFENCE;12.Nov. 1996, page11, the last line to page13, the last	1
A	US5307410A(Charles H. Bennett, Croton-On-Hudson, N.Y.;26,Apr.1994,see the whole document)	1-12

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

\* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim (S) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&amp;”document member of the same patent family

Date of the actual completion of the international search

21.Apr.2005 (21.04.2005)

Date of mailing of the international search report

11 · MAY 2005 (11 · 05 · 2005)

Name and mailing address of the ISA/CN

The State Intellectual Property Office, the P.R.China  
6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China  
100088  
Facsimile No. 86-10-62019451

Authorized officer

MA, Yan

Telephone No. (86-10)62085825



**INTERNATIONAL SEARCH REPORT**  
 Information on patent family members

 International application No.  
 PCT/CN 2004/000969

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
US6529601B1	2003.03.04	WO9744936A1	1997.11.27
		AU2906897A	1997.12.09
		EP0972373A1	2000.01.19
		JP2000511016T	2000.08.22
		CA2254767C	2002.04.16
US6438234B1	2002.08.20	CA2265553A	1998.03.12
		WO9810560A1	1998.03.12
		AU4206897A	1998.03.26
		EP0923828A	1999.06.23
		CZ9900477A3	1999.08.11
		JP2000517499TT	2000.12.26
		EP0923828B1	2004.01.28
		AT258733T	2004.02.15
		DE69727388EE	2004.03.04
		DK923828TT	2004.05.24
		ES2215238TT3	2004.10.01
US6188768B1	2001.02.13	None	
CN1135820A	1996.11.13	WO9510907A1	1995.04.20
		CA2173481A	1995.04.20
		EP0722640A1	1996.07.24
		GB2297448A	1996.07.31
		JP9505184TT	1997.05.20
		GB2297448B	1998.06.24
		EP0722640B1	1998.11.25
		DE69414874EE	1999.01.07
		ES2123825TT3	1999.01.16
		DE69414874TT	1999.05.12
		US6028935A	2000.02.22
US5307410A	1994.04.26	None	

Form PCT/ISA/210 (patent family annex) (April 2005)

**REFERENCES CITED IN THE DESCRIPTION**

*This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.*

**Patent documents cited in the description**

- US 5307410 A [0002]

**Non-patent literature cited in the description**

- *Applied Physics Letters*, 1997, vol. 77 (7), 793 [0003]